

1875.1260001/BP 1704

DIFFERENTIAL AMPLIFIER WITH LARGE INPUT COMMON MODE SIGNAL RANGE

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[0001] This application claims the benefit of U.S. Provisional Application No. 60/256,126, filed December 15, 2000, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to a method of extending an input signal range of a component that receives the input signal. Specifically, the present invention relates to a design for an amplifier that extends its input signal range. More specifically, the present invention relates to a design for a differential amplifier with a large input common mode signal range.

Background Art

[0003] Operational amplifiers are key elements used in many analog and mixed analog/digital applications. Increasingly, these applications are being realized in smaller, portable packages, which require low power supply voltages. This necessity taxes the ability of operational amplifiers to provide the large voltage swings needed to ensure a wide dynamic range.

[0004] Conventionally, operational amplifiers are implemented using differential amplifiers to increase the voltage swing. The purpose of a differential amplifier is to sense changes in its differential input signal while rejecting changes in its common mode, or average, input signal. By removing the common mode

component of an input signal, differential amplifiers can support relatively large voltage swings.

[0005] Differential amplifiers are essential building blocks of most modern IC amplifiers and are predicated on the ability to fabricate matched transistors on a chip. Differential amplifiers are particularly useful for mixed signal applications where noise generated by digital circuits can distort analog signals. Noise appearing on both input signals of a differential circuit is rejected at the output signals.

[0006] FIG. 1 is a schematic diagram of a conventional differential amplifier 100. Differential amplifier 100 comprises two transistors "M₁" 102 and "M₂" 104 with source terminals connected together. A current source "I_{TAIL}" 106 is connected in parallel with a resistor "R_{TAIL}" 108 between the source terminals and a first power supply voltage "V_{SS}" 110. (In an embodiment, V_{SS} 110 could be analog ground.) A resistor is connected to the drain terminal of each transistor. "R_{D1}" 112 is connected to the drain terminal of M₁ 102; "R_{D2}" 114 is connected to the drain terminal of M₂ 104. R_{D1} 112 and R_{D2} 114 are together connected to a second power supply voltage "V_{DD}" 116. (In an embodiment, V_{DD} 116 could be analog ground.) Differential amplifier 100 receives a differential input signal and produces a differential output signal. The differential input signal comprises a first input signal "v_{i1}" 118, which is applied to the gate terminal of M₁ 102, and a second input signal "v_{i2}" 120, which is applied to the gate terminal of M₂ 104. The differential output signal comprises a first output signal "v_{o1}" 122, which is produced at the drain terminal of M₂ 104, and a second output signal "v_{o2}" 124, which is produced at the drain terminal of M₁ 102. Preferably, differential amplifier 100 is balanced such that each component on the side of one output (e.g., M₁ 102, R_{D1} 112) corresponds to an identical component on the side of the other output (e.g., M₂ 104, R_{D2} 114).

[0007] M₁ 102 and M₂ 104 comprise a differential pair and act to control the distribution of current flowing from I_{TAIL} 106 between V_{DD} 116 and V_{SS} 110. The

sum of the current flowing through both M_1 102 and M_2 104 equals I_{TAIL} 106. So, for example, as v_{i1} 118 rises with respect to v_{i2} 120, the portion of the total current of I_{TAIL} 106 that flows through M_1 102 and R_{D1} 112 increases, while the portion that flows through M_2 104 and R_{D2} 114 decreases. More current flowing through R_{D1} 112 increases the drop in voltage across R_{D1} 112, while less current flowing through R_{D2} 114 decreases the drop in voltage across R_{D2} 114. Thus, v_{o1} 122 rises with respect to v_{o2} 124.

[0008] The differential input signal can be expressed as shown in Eq. (1):

$$\text{Eq. (1)} \quad v_{id} = v_{i1} - v_{i2},$$

while the common mode input signal can be expressed as shown in Eq. (2):

$$\text{Eq. (2)} \quad v_{ic} = [v_{i1} + v_{i2}]/2.$$

Likewise, the differential output signal can be expressed as shown in Eq. (3):

$$\text{Eq. (3)} \quad v_{od} = v_{o1} - v_{o2},$$

while the common mode output signal can be expressed as shown in Eq. (4):

$$\text{Eq. (4)} \quad v_{oc} = [v_{o1} + v_{o2}]/2.$$

[0009] As noted above, the purpose of differential amplifier 100 is to sense changes in its differential input signal v_{id} while rejecting changes in its common mode input signal v_{ic} . The ability of differential amplifier 100 to realize this goal can be expressed by several figures of merit. Particularly, the common mode rejection ratio, CMRR, is defined as shown in Eq. (5):

$$\text{Eq. (5)} \quad \text{CMRR} \equiv |A_{dm}/A_{cm}|,$$

where A_{dm} is the differential mode gain and A_{cm} is the common mode gain. A_{dm} can be expressed as shown in Eq. (6):

$$\text{Eq. (6)} \quad A_{dm} = v_{od}/v_{id} \Big|_{v_{ic}=0} = 1/2 \{ [(v_{o1} - v_{o2})/v_{i1}] + [(v_{o2} - v_{o1})/v_{i2}] \}.$$

A_{cm} can be expressed as shown in Eq. (7):

$$\text{Eq. (7)} \quad A_{cm} = v_{oc}/v_{ic} \Big|_{vid=0} = 1/2 \{ [(v_{o1} + v_{o2})/v_{i1}] + [(v_{o2} + v_{o1})/v_{i2}] \}.$$

[0010] In designing differential amplifiers, it is desired to maximize the value of CMRR. This is indicative of maximizing the desired differential mode gain and/or minimizing the undesired common mode gain. Small signal analysis of

a differential amplifier can be used to express CMRR as a function of the physical parameters internal to the transistors from which differential amplifier 100 is comprised. The small signal analysis needs to account for both differential mode and common mode operations.

[0011] FIG. 2 is a schematic diagram of a small signal model circuit 200 of differential amplifier 100. In circuit 200, M_1 102 is modeled as a current source " i_1 " 202 connected in parallel with an output resistance " r_{o1} " 204 between a node " N_0 " 206 and a node " N_1 " 208. An input resistance " $r_{\pi 1}$ " 210 is connected in series between N_0 206 and a first input signal " v_{i3} " 212. R_{D1} 112 is connected in series between N_1 208 and ground. A first output signal " v_{o3} " 214 is produced at N_1 208. Likewise, M_2 104 is modeled as a current source " i_2 " 216 connected in parallel with an output resistance " r_{o2} " 218 between N_0 206 and a node " N_2 " 220. An input resistance " $r_{\pi 2}$ " 222 is connected in series between N_0 206 and a second input signal " v_{i4} " 224. A second output signal " v_{o4} " 226 is produced at N_2 220. R_{D2} 114 is connected in series between N_2 220 and ground. R_{TAIL} 108 is connected in series between N_0 206 and ground.

[0012] The value of i_1 202 can be expressed as shown in Eq. (8):

$$\text{Eq. (8)} \quad i_1 = g_m v_1,$$

where g_m is the transconductance of M_1 102 (or M_2 104, because differential amplifier 100 is balanced), and v_1 is the voltage drop across $r_{\pi 1}$ 210.

Likewise, the value of i_2 216 can be expressed as shown in Eq. (9):

$$\text{Eq. (9)} \quad i_2 = g_m v_2,$$

where v_2 is the voltage drop across $r_{\pi 2}$ 222.

[0013] In differential mode, the value of v_{i3} 212 can be expressed as shown in Eq. (10):

$$\text{Eq. (10)} \quad v_{i3} = v_{id}/2,$$

while the value of v_{i4} 224 can be expressed as shown in Eq. (11):

$$\text{Eq. (11)} \quad v_{i4} = -v_{id}/2.$$

Likewise, the value of v_{o3} 214 can be expressed as shown in Eq. (12):

$$\text{Eq. (12)} \quad v_{o3} = v_{od}/2,$$

while the value of v_{o4} 226 can be expressed as shown in Eq. (13):

$$\text{Eq. (13)} \quad v_{o4} = -v_{od}/2.$$

[0014] Where M_1 102 and M_2 104 are MOSFETs, input resistances $r_{\pi 1}$ 210 and $r_{\pi 2}$ 222 are sufficiently large as to be considered infinite. Thus, the value of i_1 202 can be expressed as shown in Eq. (14):

$$\text{Eq. (14)} \quad i_1 = g_m v_{id}/2,$$

and the value of i_2 216 can be expressed as shown in Eq. (15):

$$\text{Eq. (15)} \quad i_2 = -g_m v_{id}/2.$$

[0015] Because differential amplifier 100 is balanced and the input signals are driven by equal but opposite voltages, there is no variation in the voltage across R_{TAIL} 108. In small signal analysis, this condition is effectively the same as connecting N_0 206 to ground. Therefore, further analysis of small signal model circuit 200 operating in differential mode can be simplified by analyzing a small signal differential mode model half circuit.

[0016] FIG. 3 is a schematic diagram of a small signal differential mode model half circuit 300. In half circuit 300, i_1 202, r_{o1} 204, and R_{D1} 112 are connected in parallel between N_0 206 and N_1 208. N_0 206 is connected to ground. v_{o3} 214 is produced at N_1 208. Recalling Eqs. (6), (12), and (14), A_{dm} can be expressed as shown in Eq. (16):

$$\text{Eq. (16)} \quad A_{dm} = -g_m R,$$

where R is the effective resistance of the parallel combination of r_{o1} 204 and R_{D1} 112.

[0017] Returning to FIG. 2, in common mode, the values of v_{i3} 212 and v_{i4} 224 can be expressed as shown in Eq. (17):

$$\text{Eq. (17)} \quad v_{i3} = v_{i4} = v_{ic}.$$

Likewise, the values of v_{o3} 214 and v_{o4} 226 can be expressed as shown in Eq. (18):

$$\text{Eq. (18)} \quad v_{o3} = v_{o4} = v_{oc}.$$

[0018] Where M_1 102 and M_2 104 are MOSFETs, input resistances $r_{\pi 1}$ 210 and $r_{\pi 2}$ 222 are sufficiently large as to be considered infinite. Thus, the values of i_1 202 and i_2 216 can be expressed as shown in Eq. (19):

$$\text{Eq. (19)} \quad i_1 = i_2 = g_m v_{ic}.$$

[0019] Because differential amplifier 100 is balanced and the input signals are driven by equal voltages, further analysis of small signal model circuit 200 operating in common mode can be simplified by analyzing a small signal common mode model half circuit.

[0020] FIG. 4 is a schematic diagram of a small signal common mode model half circuit 400. In half circuit 400, a resistor "R_{TAIL2}" 402 is connected between N₀ 206 and ground. The value of R_{TAIL2} 402 can be expressed as shown in Eq. (20):

$$\text{Eq. (20)} \quad R_{TAIL2} = 2 \times R_{TAIL}.$$

Conceptually, R_{TAIL} 108 in small signal model circuit 200 is first modeled as a parallel combination of two resistors connected between N₀ 206 and ground. Each resistor in the parallel combination has a resistance value equal to R_{TAIL2} 402, such that the resistance value of the parallel combination remains equal to R_{TAIL} 108. This enables small signal model circuit 200 to be reconfigured as small signal common mode model half circuit 400 so that it accounts for the voltage drop across R_{TAIL} 108.

[0021] Also in half circuit 400, i_1 202 is connected between N₀ 206 and N₁ 208 so that i_1 202 and R_{TAIL2} 402 are connected in series between N₁ 208 and ground. Additionally, r_{o1} 204 and R_{D1} 112 are connected in parallel between N₁ 208 and ground. v_{o3} 214 is produced at N₁ 208. Recalling Eqs. (7), (18), (19), and (20), A_{cm} can be expressed as shown in Eq. (21):

$$\text{Eq. (21)} \quad A_{cm} = - g_m R / [1 + g_m R_{TAIL2}],$$

where R is the effective resistance of the parallel combination of r_{o1} 204 and R_{D1} 112.

[0022] Thus, recalling Eqs. (5), (16), and (21), CMRR, as a function of the physical parameters internal to the transistors from which differential amplifier 100 is comprised, can be expressed as shown in Eq. (22):

$$\text{Eq. (22) CMRR} = 1 + g_m R_{\text{TAIL2}}.$$

[0023] In practical implementations, differential amplifiers are realized using active devices for current sources, and in most cases also for loads. Active devices provide large values of resistance, while dropping less voltage and consuming less die area than passive resistors.

[0024] FIG. 5 is a schematic diagram of a conventional differential amplifier 500 with active loads. Differential amplifier 500 comprises a differential pair 502 of amplifying transistors M_1 102 and M_2 104 with source terminals connected together. A load transistor is connected to the drain terminal of each amplifying transistor. " M_3 " 504 is connected to the drain terminal of M_1 102; " M_4 " 506 is connected to the drain terminal of M_2 104. M_3 504 and M_4 506 are together connected to power supply voltage V_{DD} 116. A first bias voltage " V_{biasp} " 508 holds load transistors M_3 504 and M_4 506 in saturation. A fifth transistor " M_5 " 510 provides a current source for differential amplifier 500. M_5 510 is connected between the source terminals of M_1 102 and M_2 104, and power supply voltage V_{SS} 110. A second bias voltage " V_{biasn} " 512 holds transistor M_5 510 in saturation. First input signal v_{i1} 118 is applied to the gate terminal of M_1 102 and first output signal v_{o1} 122 is produced at the drain terminal of M_2 104. Second input signal v_{i2} 120 is applied to the gate terminal of M_2 104 and second output signal v_{o2} 124 is produced at the drain terminal of M_1 102.

[0025] In differential amplifier 500, M_1 102, M_2 104, and M_5 510 are NMOSFETs, while M_3 504 and M_4 506 are PMOSFETs. However, one skilled in the art would recognize that other transistor configurations could also be used. Preferably, differential amplifier 500 is balanced such that each component on the side of one output (e.g., M_1 102, M_3 504) corresponds to an identical component on the side of the other output (e.g., M_2 104, M_4 506).

[0026] Unfortunately, while the use of active devices for current sources and loads has several advantages, it also presents the problem of limiting the input common mode signal range. (It is desirable to have the input common mode signal range from V_{SS} to V_{DD} .) This is due to the need to hold current source transistors in saturation. This common mode confinement is particularly difficult in applications seeking to meet, for example, IEEE Std 1596.3-1996 for Low-Voltage Differential Signals for Scalable Coherent Interface, which requires a large input common mode signal range. An analysis of the input common mode signal range for differential amplifier 500 highlights this limitation.

[0027] For differential amplifier 500, the lower limit of v_{ic} can be expressed as shown in Eq. (23):

$$\text{Eq. (23)} \quad v_{ic} > V_{SS} + v_{Tn} + v_{ovM5},$$

where v_{Tn} is the threshold voltage of M_1 102 (or M_2 104), and v_{ovM5} is the overdrive voltage of M_5 510.

[0028] Likewise, the upper limit of v_{ic} can be expressed as shown in Eq. (24):

$$\text{Eq. (24)} \quad v_{ic} < V_{DD} + v_{Tn} - v_{ovload},$$

where v_{ovload} is the overdrive voltage of M_3 504 (or M_4 506). Normally, $v_{Tn} > v_{ovload}$. Thus, the analysis shows that, while the upper limit of the input common mode signal range desirably can be maintained greater than or equal to V_{DD} , the lower limit of the input common mode signal range undesirably often must be greater than V_{SS} .

[0029] Conventionally, this problem has been addressed by configuring a differential amplifier to have two differential pairs to increase the input common mode signal range. FIG. 6 is a schematic diagram of a conventional differential amplifier 600 with two differential pairs. Differential amplifier 600 comprises differential pair 502 of amplifying transistors M_1 102 and M_2 104 with source terminals connected together. M_5 510 is connected between V_{SS} 110 and the source terminals of M_1 102 and M_2 104. V_{biasn} 512 holds transistor M_5 510 in saturation.

[0030] Differential amplifier 600 further comprises a second differential pair 602 of amplifying transistors "M₆" 604 and "M₇" 606 with source terminals connected together. A sixth transistor "M₈" 608 provides a current source for amplifying transistors M₆ 604 and M₇ 606. M₈ 608 is connected between V_{DD} 116 and the source terminals M₆ 604 and M₇ 606. A third bias voltage "V_{biasp2}" 610 holds transistor M₈ 608 in saturation.

[0031] First input signal v_{i1} 118 is applied to the gate terminals of both M₁ 102 and M₆ 604. Second input signal v_{i2} 120 is applied to the gate terminals of both M₂ 104 and M₇ 606. First output signal v_{o1} 122 is produced at the drain terminal of M₂ 104. Second output signal v_{o2} 124 is produced at the drain terminal of M₁ 102. A third output signal "v_{o5}" 612 is produced at the drain terminal of M₇ 606. A fourth output signal "v_{o6}" 614 is produced at the drain terminal of M₆ 604.

[0032] Differential amplifier 600 requires a subsequent stage, usually a cascode structure, to provide loads for amplifying transistors M₁ 102, M₂ 104, M₆ 604, and M₇ 606, and to process the four output signals v_{o1} 122, v_{o2} 124, v_{o5} 612, and v_{o6} 614.

[0033] In differential amplifier 600, M₁ 102, M₂ 104, and M₅ 510 are NMOSFETs, while M₆ 604, M₇ 606, and M₈ 608 are PMOSFETs. However, one skilled in the art would recognize that other transistor configurations could also be used. Preferably, differential amplifier 600 is balanced such that each component on the side of one output (e.g., M₁ 102, M₆ 604) corresponds to an identical component on the side of the other output (e.g., M₂ 104, M₇ 606).

[0034] An analysis of the input common mode signal range for differential amplifier 600 shows that it is wider than that of differential amplifier 500. For differential amplifier 600, the lower limit of v_{ic} can be expressed as shown in Eq. (25):

$$\text{Eq. (25)} \quad v_{ic} > V_{ss} + v_{Tp} + v_{ovloadn},$$

where v_{Tp} is the threshold voltage of M_6 604 (or M_7 606), and $v_{ovloadn}$ is the overdrive voltage of a NMOSFET load in the subsequent stage (not shown). Normally, $v_{Tp} < 0$, but $|v_{Tp}| > |v_{ovloadn}|$.

[0035] Likewise, the upper limit of v_{ic} can be expressed as shown in Eq. (26):

$$\text{Eq. (26)} \quad v_{ic} < V_{DD} + v_{Tn} - v_{ovloadp},$$

where $v_{ovloadp}$ is the overdrive voltage of a PMOSFET load in the subsequent stage (not shown). Thus, when $v_{ovloadn} = v_{ovMS}$ and $v_{ovloadp} = v_{ovload}$, comparisons of Eq. (23) with Eq. (25), and Eq. (24) with Eq. (26) show that the upper limit of the input common mode signal range desirably can be maintained greater than or equal to V_{DD} , and the lower limit of the input common mode signal range desirably can also be maintained less than or equal to V_{SS} .

[0036] However, while differential amplifier 600 maximizes the input common mode signal range, the design presents several problems that detract from its usefulness. Significant power is dissipated and valuable substrate area is consumed to support the second current source transistor and to support the subsequent stage needed to provide loads for the amplifying transistors and to process the two additional output signals. Also, successful implementation of differential amplifier 600 depends on an ability to fabricate differential pairs 502 and 602 with matching gains and similar transient behaviors. This is very difficult to realize when differential pair 502 comprises NMOSFETs and differential pair 602 comprises PMOSFETs.

[0037] What is needed is a differential amplifier design that optimizes the input common mode signal range, power dissipated, and substrate area consumed, and avoids the difficulty of matching gains between a differential pair of NMOSFETs and a differential pair of PMOSFETs.

BRIEF SUMMARY OF THE INVENTION

[0038] The present invention relates to a method of extending an input signal range of a component that receives the input signal. Specifically, the present invention relates to a design for an amplifier that extends its input signal range. More specifically, the present invention relates to a design for a differential amplifier with a large input common mode signal range.

[0039] The differential amplifier of the present invention comprises two differential pairs. Each differential pair comprises two amplifying MOSFETs with their source terminals connected together. The drain terminals of corresponding amplifying MOSFETs in each differential pair are also connected together and to the drain terminal of a corresponding load MOSFET. The amplifying MOSFETs are of the same type: either NMOSFETs or PMOSFETs. The load MOSFETs are of the type opposite that of the amplifying MOSFETs.

[0040] A bias voltage holds the load MOSFETs in saturation. The bias voltage has the effect of limiting the voltages of an input common mode signal to a range less than the desirable voltage range. The desirable voltage range spans between the voltages that supply power to the amplifier.

[0041] A source follower is connected to the gate terminal of each amplifying MOSFET in one of the differential pairs. Each source follower comprises a driven MOSFET and a non-driven MOSFET. They are of the type opposite that of the amplifying MOSFETs. The source terminal of each driven MOSFET and the drain terminal of the corresponding non-driven MOSFET are connected to the gate terminal of the corresponding amplifying MOSFET. An input signal is applied at two terminals in each half of the differential amplifier: the gate terminal of the driven MOSFET of the source follower and the gate terminal of the amplifying MOSFET not connected to the source follower. The source follower acts to offset the voltage of the input signal to compensate for the range loss due to the bias voltage.

[0042] The differential amplifier further comprises a pair of switch MOSFETs with their source terminals connected together and to a current source MOSFET. Another bias voltage holds the current source MOSFET in saturation. The drain terminal of one of the switch MOSFETs is connected to the source terminals of the amplifying MOSFETs in the differential pair driven by the source followers. A reference voltage is applied to the gate terminal of this switch MOSFET. The drain terminal of the other switch MOSFET is connected to the source terminals of the amplifying MOSFETs in the other differential pair. An input common mode signal is applied to the gate terminal of this switch MOSFET. The other bias voltage and the threshold voltages of the switch MOSFETs also have the effect of limiting the voltages of the input common mode signal to a range less than the desirable voltage range.

[0043] The switch MOSFETs act to control the distribution of the total current flowing from the current source MOSFET. So, for example, when the input common mode signal voltage equals the reference voltage, equal portions of the total current flow through both switch MOSFETs; when the input common mode signal voltage is greater than the reference voltage, a greater portion of the total current flows through the MOSFET switch tied to the differential pair directly driven by the input signals; and when the input common mode signal voltage is less than the reference voltage, a greater portion of the total current flows through the MOSFET switch tied to the differential pair driven by the source followers.

[0044] A differential input signal applied to the differential amplifier comprises two separate signals. Each separate signal is applied to the gate terminals of both the amplifying MOSFET in the differential pair not driven by the source follower and the driven MOSFET of the source follower. Each source follower acts to offset the voltage of its input signal to compensate for the range loss due to the bias voltages and the threshold voltages of the switch MOSFETs.

[0045] When equal portions of the total current flow through both switch MOSFETs, both differential pairs work equally to amplify the input signals; when

a greater portion of the total current flows through the MOSFET switch tied to the differential pair directly driven by the input signals, that differential pair works dominantly; when a greater portion of the total current flows through the MOSFET switch tied to the differential pair driven by the source followers, that differential pair works dominantly.

[0046] Advantageously, the differential amplifier optimizes its input common mode signal range using differential pairs of the same type. This mitigates difficulties faced in fabricating differential pairs with matching gains and similar transient behaviors.

[0047] Furthermore, the differential amplifier does not require a subsequent stage to provide loads for its amplifying MOSFETs or to process additional output signals. Thus, it consumes both less power and less substrate area. Additional savings in power and substrate area are realized because the differential pairs both draw current from the same current source MOSFET.

[0048] Yet another advantage provided by the design of the differential amplifier is a larger common mode rejection ratio because the switch MOSFETs are connected in a cascode configuration and act to maintain the total current more constant over the input common mode voltage range.

BRIEF DESCRIPTION OF THE FIGURES

[0049] The accompanying drawings, which are incorporated herein and form part of the specification, illustrate the present invention and, together with the description, further serve to explain the principles of the invention and to enable a person skilled in the pertinent art to make and use the invention.

[0050] FIG. 1 is a schematic diagram of a conventional differential amplifier 100.

[0051] FIG. 2 is a schematic diagram of a small signal model circuit 200 of differential amplifier 100.

[0052] FIG. 3 is a schematic diagram of a small signal differential mode model half circuit 300.

[0053] FIG. 4 is a schematic diagram of a small signal common mode model half circuit 400.

[0054] FIG. 5 is a schematic diagram of a conventional differential amplifier 500 with active loads.

[0055] FIG. 6 is a schematic diagram of a conventional differential amplifier 600 with two differential pairs.

[0056] FIG. 7 is a schematic diagram of a differential amplifier 700 configured to be a NMOSFET embodiment of the present invention.

[0057] FIG. 8 is a schematic diagram of a small signal model circuit 800 of differential pair 502 of differential amplifier 700.

[0058] FIG. 9 is a schematic diagram of a circuit 900 for obtaining v_{ic} 736 from v_{i1} 118 and v_{i2} 120.

[0059] FIG. 10 is a schematic diagram of a differential amplifier 1000 configured to be a PMOSFET embodiment of the present invention.

[0060] FIG. 11 is a schematic diagram of a single-input amplifier 1100 of the present invention.

[0061] FIG. 12 shows a flow chart of a method 1200 for extending an input signal range of a component that receives a signal.

[0062] The preferred embodiments of the invention are described with reference to the figures where like reference numbers indicate identical or functionally similar elements. Also in the figures, the left most digit of each reference number identifies the figure in which the reference number is first used.

DETAILED DESCRIPTION OF THE INVENTION

[0063] The present invention relates to a method of extending an input signal range of a component that receives the input signal. Specifically, the present invention relates to a design for an amplifier that extends its input signal range. More specifically, the present invention relates to a design for a differential amplifier with a large input common mode signal range.

[0064] FIG. 7 is a schematic diagram of a differential amplifier 700 configured to be a NMOSFET embodiment of the present invention. Differential amplifier 700 comprises first differential pair 502 of amplifying NMOSFETs M_1 102 and M_2 104 with source terminals connected at a first node "N₃" 702, and a second differential pair 704 of amplifying NMOSFETs "M₉" 706 and "M₁₀" 708 with source terminals connected at a second node "N₄" 710. First and second differential pairs 502, 704 are connected in parallel. The drain terminals of M_1 102 and M_9 706 are connected at a third node "N₅" 712; the drain terminals of M_2 104 and M_{10} 708 are connected at a fourth node "N₆" 714. M_3 504 is connected as a load PMOSFET between V_{DD} 116 and N₅ 712; M_4 506 is connected as a load PMOSFET between V_{DD} 116 and N₆ 714. First bias voltage V_{biasp} 508 holds M_3 504 and M_4 506 in saturation.

[0065] A first switch NMOSFET "M₁₁" 716 and a second switch NMOSFET "M₁₂" 718 have their source terminals connected at a fifth node "N₇" 720. The drain terminal of M_{11} 716 is connected to N₃ 702; the drain terminal of M_{12} 718 is connected to N₄ 710. M_{11} 716 and M_{12} 718 together comprise a differential switch circuit. Current source NMOSFET M_5 510 is connected between V_{SS} 110 and N₇ 720. Second bias voltage V_{biasn} 512 holds M_5 510 in saturation.

[0066] The source terminal of a first voltage offset PMOSFET "M₁₃" 722 is connected with the gate terminal of M_9 706 at a sixth node "N₈" 724. The drain terminal of M_{13} 722 is connected to V_{SS} 110. A second current source PMOSFET "M₁₄" 726 is connected between V_{DD} 116 and N₈ 724. The source terminal of a

second voltage offset PMOSFET "M₁₅" 728 is connected with the gate terminal of M₁₀ 708 at a seventh node "N₉" 730. The drain terminal of M₁₅ 728 is connected to V_{SS} 110. A third current source PMOSFET "M₁₆" 732 is connected between V_{DD} 116 and N₉ 730. A third bias voltage "V_{biasp3}" 734 holds both M₁₄ 726 and M₁₆ 732 in saturation.

[0067] First input signal v_{i1} 118 is applied to the gate terminals of both M₁ 102 and M₁₃ 722 at a first input terminal "N₁₀" 736; second input signal v_{i2} 120 is applied to the gate terminals of both M₂ 104 and M₁₅ 730 at a second input terminal "N₁₁" 738. N₁₀ 736 and N₁₁ 738 together comprise a differential input. First output signal v_{o1} 122 is produced at N₆ 714, which is a first output terminal; second output signal v_{o2} 124 is produced at N₅ 712, which is a second output terminal. N₆ 714 and N₅ 712 together comprise a differential output. An input common mode signal (see Eq. (2)) "v_{ic}" 747 is applied to the gate terminal of M₁₁ 716; a reference voltage "v_{ref}" 742 is applied to the gate terminal of M₁₂ 718.

[0068] Preferably, differential amplifier 700 is balanced such that each component on the side of one output (e.g., M₁ 102, M₃ 504, M₉ 706, M₁₁ 716, M₁₃ 722, M₁₄ 726) corresponds to an identical component on the side of the other output (e.g., M₂ 104, M₄ 506, M₁₀ 708, M₁₂ 718, M₁₅ 728, M₁₆ 732).

[0069] Configured as they are, M₁₃ 722 and M₁₄ 726 form a first source follower 744, where M₁₃ 722 is the driven PMOSFET and M₁₄ 726 is the non-driven PMOSFET. Thus, the voltage at N₈ 724, v_{N8}, can be expressed as shown in Eq. (27):

$$\text{Eq. (27)} \quad v_{N8} = v_{i1} - v_{TpM13} + v_{ovM13},$$

where v_{TpM13} is the threshold voltage of M₁₃, and v_{ovM13} is the overdrive voltage of M₁₃. Likewise, M₁₅ 728 and M₁₆ 732 form a second source follower 746, where M₁₅ 728 is the driven PMOSFET and M₁₆ 732 is the non-driven PMOSFET. Thus, the voltage at N₉ 730, v_{N9}, can be expressed as shown in Eq. (28):

$$\text{Eq. (28)} \quad v_{N9} = v_{i2} - v_{TpM15} + v_{ovM15},$$

where v_{TpM15} is the threshold voltage of M_{15} , and v_{ovM15} is the overdrive voltage of M_{15} . Normally, $v_{TpM13} < 0$, and $v_{TpM15} < 0$. Thus, M_{13} 722 and M_{15} 728 act to level shift, respectively, v_{i1} 118 and v_{i2} 120, by the sum of the absolute values of the threshold and overdrive voltages of M_{13} 722 (or equivalently, M_{15} 728). First and second source followers 744, 746 together comprise a differential offset circuit.

[0070] First differential pair 502 directly amplifies v_{i1} and v_{i2} , while second differential pair 704 amplifies v_{N8} and v_{N9} . Hence, second differential pair 704 indirectly amplifies v_{i1} and v_{i2} because of the voltage drop across M_{13} 722 and M_{15} 728. Based on the instantaneous value of v_{ic} 736, M_{11} 716 and M_{12} 718 act to control which of first and second differential pairs 502, 704 dominates the other during amplification. The effect of this arrangement is that each differential pair 502, 704 has its own corresponding input common mode signal range such that the overall input common mode signal range of differential amplifier 700 is improved. For example, first differential pair 502 dominates over a first input common mode signal range, and second differential pair 704 dominates over a second input common mode signal range.

[0071] M_{11} 716 controls a first current flow to first differential pair 502 based on v_{ic} 740. Likewise, M_{12} 718 controls a second current flow to second differential pair 704. Therefore, M_{11} 716 and M_{12} 718 determine the respective gain of differential pairs 502, 704. The sum of current flowing through both M_{11} 716 and M_{12} 718 equals the total current flowing through M_5 510. So, for example, when v_{ic} 740 equals v_{ref} 742, equal portions of the total current flow through M_{11} 716 and M_{12} 718; when v_{ic} 740 is greater than v_{ref} 742, a greater portion of the total current flows through M_{11} 716; and when v_{ic} 740 is less than v_{ref} 742, a greater portion of the total current flows through M_{12} 718.

[0072] When equal portions of the total current flow through both M_{11} 716 and M_{12} 718, both differential pairs 502, 704 provide equal amplification for v_{i1} and v_{i2} . When a greater portion of the total current flows through M_{11} 716, first differential pair 502 provides more amplification than second differential pair

704. When a greater portion of the total current flows through M_{12} 718, second differential pair 704 provides more amplification than first differential pair 502.

[0073] In an embodiment, v_{ref} 740 is set at a voltage level greater than the lower limit of the input common mode signal range of differential pair 502. However, the skilled artisan would recognize other voltage levels to which v_{ref} 740 could be set.

[0074] An analysis of the input common mode signal range for differential amplifier 700 shows that it is wider than that of differential amplifier 500. For differential amplifier 700, the lower limit of v_{ic} can be expressed as shown in Eq. (29):

$$Eq. (29) v_{ic} > V_{SS} + v_{Tn2} + v_{ovM5} + v_{dsM12} - v_{poffset},$$

where v_{Tn2} is the threshold voltage of M_9 706 (or M_{10} 708), v_{ovM5} is the overdrive voltage of M_5 510, v_{dsM12} is the drain-to-source voltage of M_{12} 718, and $v_{poffset}$ is the sum of the absolute values of the threshold and overdrive voltages of M_{13} 722 (or M_{15} 728). M_{12} 718 works in the linear region as a switch. It is possible that $v_{poffset} > v_{Tn2} + v_{ovM5} + v_{dsM12}$.

[0075] Likewise, the upper limit of v_{ic} can be expressed as shown in Eq. (30):

$$Eq. (30) v_{ic} < V_{DD} + v_{Tn} - v_{ovload},$$

where v_{Tn} is the threshold voltage of M_1 102 (or M_2 104), and v_{ovload} is the overdrive voltage of M_3 504 (or M_4 506). By comparing Eq. (23) with Eq. (29), it can be seen that the upper limit of the input common mode signal range desirably can be maintained greater than or equal to V_{DD} . Similarly, by comparing Eq. (24) with Eq. (30), it can be seen that the lower limit of the input common mode signal range desirably can be maintained less than or equal to V_{SS} .

[0076] Advantageously, differential amplifier 700 optimizes its input common mode signal range using differential pairs of NMOSFETs. This mitigates difficulties faced in fabricating differential pairs with matching gains and similar transient behaviors.

[0077] Also, unlike differential amplifier 600, differential amplifier 700 does not require a subsequent stage to provide loads for its amplifying transistors or to process additional output signals. Thus, in comparison with differential amplifier 600, differential amplifier 700 consumes both less power and less substrate area.

[0078] Further savings in power and substrate area are realized because differential pairs 502, 704 both draw current from current source transistor M_5 510. While differential amplifier 700 does include current source transistors M_{14} 726 and M_{16} 732, these devices are sized at an order of magnitude (about ten times) smaller than that of current source transistor M_8 608 in differential amplifier 600. Therefore, when corresponding devices of differential amplifiers 600 and 700 are similarly sized, differential amplifier 700 consumes less power and occupies less substrate area.

[0079] Yet another advantage provided by the design of differential amplifier 700, in comparison with differential amplifier 600, is a larger CMRR. Recalling that the CMRR of differential amplifier 100 was derived through analysis of small signal model circuit 200 in FIG. 2, a similar analysis can be performed on a small signal model circuit for differential amplifier 700 to derive its CMRR.

[0080] FIG. 8 is a schematic diagram of a small signal model circuit 800 of differential pair 502 of differential amplifier 700. Because differential pair 502 includes amplifying transistors M_1 102 and M_2 104, which are common to differential amplifiers 100, 600, and 700, small signal model circuit 800 is similar to the topology of small signal model circuit 200 with some differences as explained below.

[0081] While differential amplifier 100 uses resistors R_{D1} 112 and R_{D2} 114 for passive loads, differential amplifier 700 uses transistors M_3 504 and M_4 506 for active loads. Thus, R_{D1} 112 in circuit 200 is replaced in circuit 800 by a resistor " r_{0M3} " 802, which corresponds to the output resistance of M_3 504. Likewise, R_{D2} 114 in circuit 200 is replaced in circuit 800 by a resistor " r_{0M4} " 804, which

corresponds to the output resistance of M_4 506. A small signal model circuit for differential amplifier 600 (not shown) would include a similar replacement.

[0082] Similarly, while differential amplifier 100 uses (ideal) current source I_{TAIL} 106 connected in parallel with resistor R_{TAIL} 108, differential pair 502 (in both differential amplifiers 600 and 700) uses current source transistor M_5 510. Thus, R_{TAIL} 108 in circuit 200 is replaced in circuit 800 by a resistor " r_{0M5} " 806, which corresponds to the output resistance of M_5 510.

[0083] However, unlike differential amplifiers 100 or 600, differential amplifier 700 also includes switch transistors M_{11} 716 and M_{12} 718. Therefore, circuit 800 also includes a resistor " r_{0M11} " 808, which corresponds to the output resistance of M_{11} 716, connected in series with r_{0M5} 806 between N_0 206 and ground.

[0084] So, while analysis of small signal model circuit 200 yielded Eq. (22) as an expression for the CMRR of differential amplifiers 100 and 600, a parallel analysis of small signal model circuit 800 shows that the CMRR of differential pair 502 of differential amplifier 700 can be expressed as shown in Eq. (31):

$$\text{Eq. (31) CMRR} = [1 + 2g_m \times (r_{0M5} + r_{0M11})].$$

[0085] A similar analysis of differential pair 704 shows that its CMRR can be expressed as shown in Eq. (32):

$$\text{Eq. (32) CMRR} = [1 + 2g_m \times (r_{0M5} + r_{0M12})],$$

where r_{0M12} is the output resistance of M_{12} 718. (Normally, $r_{0M11} = r_{0M12}$.) Thus, the CMRR of differential amplifier 700 is larger than that of differential amplifiers 100 or 600, when $(r_{0M5} + r_{0M12}) > R_{TAIL}$.

[0086] FIG. 9 is a schematic diagram of a circuit 900 for obtaining v_{ic} 740 from v_{i1} 118 and v_{i2} 120. In circuit 900, a first division resistor " R_{div1} " 902 is connected in series between a first node " N_{12} " 904 and a second node " N_{13} " 906. A second division resistor " R_{div2} " 908 is connected in series between N_{13} 906 and a third node " N_{14} " 910. The resistance of R_{div1} equals the resistance of R_{div2} . First input signal v_{i1} 118 is applied to N_{12} 904; second input signal v_{i2} 120 is applied to N_{14} 910. Input common mode signal v_{ic} 740 is produced at N_{13} 906. One skilled in

the art would recognize other means by which v_{ic} 740 could be obtained from v_{i1} 118 and v_{i2} 120. The present invention is not limited to use of circuit 900.

[0087] FIG. 10 is a schematic diagram of a differential amplifier 1000 configured to be a PMOSFET embodiment of the present invention. Differential amplifier 1000 comprises first differential pair 602 of amplifying PMOSFETs M_6 604 and M_7 606 with source terminals connected at a first node "N₁₃" 1002, and a second differential pair 1004 of amplifying PMOSFETs "M₁₇" 1006 and "M₁₈" 1008 with source terminals connected at a second node "N₁₄" 1010. First and second differential pairs 602, 1004 are connected in parallel. The drain terminals of M_6 604 and M_{17} 1006 are connected at a third node "N₁₅" 1012; the drain terminals of M_7 606 and M_{18} 1008 are connected at a fourth node "N₁₆" 1014. A first load transistor "M₁₉" 1016 is connected as a load NMOSFET between V_{ss} 110 and N₁₅ 1012; a second load transistor "M₂₀" 1018 is connected as a load NMOSFET between V_{ss} 110 and N₁₆ 1014. A first bias voltage "V_{biasn2}" 1020 holds M₁₉ 1016 and M₂₀ 1018 in saturation.

[0088] A first switch PMOSFET "M₂₁" 1022 and a second switch PMOSFET "M₂₂" 1024 have their source terminals connected at a fifth node "N₁₇" 1026. The drain terminal of M₂₁ 1022 is connected to N₁₃ 1002; the drain terminal of M₂₂ 1024 is connected to N₁₄ 1010. M₂₁ 1022 and M₂₂ 1024 together comprise a differential switch circuit. Current source PMOSFET M₈ 608 is connected between V_{dd} 116 and N₁₇ 1026. Second bias voltage V_{biasp2} 610 holds M₈ 608 in saturation.

[0089] The source terminal of a first voltage offset NMOSFET "M₂₃" 1028 is connected with the gate terminal of M₁₇ 1006 at a sixth node "N₁₈" 1030. The drain terminal of M₂₃ 1028 is connected to V_{dd} 116. A second current source NMOSFET "M₂₄" 1032 is connected between V_{ss} 110 and N₁₈ 1030. The source terminal of a second voltage offset NMOSFET "M₂₅" 1034 is connected with the gate terminal of M₁₈ 1008 at a seventh node "N₁₉" 1036. The drain terminal of M₂₅ 1034 is connected to V_{dd} 116. A third current source NMOSFET "M₂₆" 1038

is connected between V_{SS} 110 and N_{19} 1036. A third bias voltage " V_{bias3} " 1040 holds both M_{24} 1032 and M_{26} 1038 in saturation.

[0090] First input signal v_{i1} 118 is applied to the gate terminals of both M_6 604 and M_{17} 1006 at a first input terminal " N_{20} " 1042; second input signal v_{i2} 120 is applied to the gate terminals of both M_7 606 and M_{18} 1008 at a second input terminal " N_{21} " 1044. N_{20} 1042 and N_{21} 1044 together comprise a differential input. First output signal v_{o1} 122 is produced at N_{16} 1014, which is a first output terminal; second output signal v_{o2} 124 is produced at N_{15} 1012, which is a second output terminal. N_{16} 1014 and N_{15} 1012 together comprise a differential output. Input common mode signal (see Eq. (2)) v_{ic} 740 is applied to the gate terminal of M_{21} 1022; reference voltage v_{ref} 742 is applied to the gate terminal of M_{22} 1024.

[0091] Preferably, differential amplifier 1000 is balanced such that each component on the side of one output (e.g., M_6 604, M_{17} 1006, M_{19} 1016, M_{21} 1022, M_{23} 1028, M_{24} 1032) corresponds to an identical component on the side of the other output (e.g., M_7 606, M_{18} 1008, M_{20} 1018, M_{22} 1024, M_{25} 1034, M_{26} 1038).

[0092] Configured as they are, M_{23} 1028 and M_{24} 1032 form a first source follower 1046, where M_{23} 1028 is the driven NMOSFET and M_{24} 1032 is the non-driven NMOSFET. Thus, the voltage at N_{18} 1030, v_{N18} , can be expressed as shown in Eq. (33):

$$\text{Eq. (33)} \quad v_{N18} = v_{i1} - v_{TnM23} - v_{ovM23},$$

where v_{TnM23} is the threshold voltage of M_{23} , and v_{ovM23} is the overdrive voltage of M_{23} . Likewise, M_{25} 1034 and M_{26} 1038 form a second source follower 1048, where M_{25} 1034 is the driven NMOSFET and M_{26} 1038 is the non-driven NMOSFET. Thus, the voltage at N_{19} 1036, v_{N19} , can be expressed as shown in Eq. (34):

$$\text{Eq. (34)} \quad v_{N19} = v_{i2} - v_{TnM25} - v_{ovM25},$$

where v_{TnM25} is the threshold voltage of M_{25} , and v_{ovM25} is the overdrive voltage of M_{25} . Thus, M_{23} 1028 and M_{25} 1034 act to level shift, respectively, v_{i1} 118 and

v_{i2} 120, the sum of the absolute values of the threshold and overdrive voltages of M_{23} 1028 (or equivalently, M_{25} 1034). First and second source followers 1046, 1048 together comprise a differential offset circuit.

[0093] First differential pair 602 directly amplifies v_{i1} and v_{i2} , while second differential pair 1004 amplifies v_{N18} and v_{N19} . Hence, second differential pair 1004 indirectly amplifies v_{i1} and v_{i2} because of the voltage drop across M_{23} 1028 and M_{25} 1034. Based on the instantaneous value of v_{ic} 736, M_{21} 1022 and M_{22} 1024 act to control which of first and second differential pairs 602, 1004 dominates the other during amplification. The effect of this arrangement is that each differential pair 602, 1004 has its own corresponding input common mode signal range such that the overall input common mode signal range of differential amplifier 1000 is improved. For example, first differential pair 602 dominates over a first input common mode signal range, and second differential pair 1004 dominates over a second input common mode signal range.

[0094] M_{21} 1022 controls a first current flow to first differential pair 602 based on v_{ic} 740. Likewise, M_{22} 1024 controls a second current flow to second differential pair 1004. Therefore, M_{21} 1022 and M_{22} 1024 determine the respective gain of differential pairs 602, 1004. The sum of current flowing through both M_{21} 1022 and M_{22} 1024 equals the total current flowing through M_8 608. So, for example, when v_{ic} 740 equals v_{ref} 742, equal portions of the total current flow through M_{21} 1022 and M_{22} 1024; when v_{ic} 740 is less than v_{ref} 742, a greater portion of the total current flows through M_{21} 1022; and when v_{ic} 740 is greater than v_{ref} 742, a greater portion of the total current flows through M_{22} 1024.

[0095] When equal portions of the total current flow through both M_{21} 1022 and M_{22} 1024, both differential pairs 602, 1004 provide equal amplification for v_{i1} and v_{i2} . When a greater portion of the total current flows through M_{21} 1022, first differential pair 602 provides more amplification than second differential pair 1004. When a greater portion of the total current flows through M_{22} 1024, second differential pair 1004 provides more amplification than first differential pair 502.

[0096] In an embodiment, v_{ref} 740 is set at a voltage level lesser than the upper limit of the input common mode signal range of differential pair 602. However, the skilled artisan would recognize other voltage levels to which v_{ref} 740 could be set.

[0097] An analysis of the input common mode signal range for differential amplifier 1000 shows that it is wider than that of differential amplifier 500. For differential amplifier 1000, the lower limit of v_{ic} can be expressed as shown in Eq. (35):

$$\text{Eq. (35)} \quad v_{ic} > V_{SS} + v_{Tp2} + v_{ovload2},$$

where v_{Tp2} is the threshold voltage of M_6 604 (or M_7 606), and $v_{ovload2}$ is the overdrive voltage of M_{19} 1016 (or M_{20} 1016). Normally, $v_{Tp2} < 0$, but $|v_{Tp2}| > |v_{ovload2}|$.

[0098] Likewise, the upper limit of v_{ic} can be expressed as shown in Eq. (36):

$$\text{Eq. (36)} \quad v_{ic} < V_{DD} + v_{Tp3} - v_{ovM8} + v_{dsM22} + v_{noffset},$$

where v_{Tp3} is the threshold voltage of M_{17} 1006 (or M_{18} 1008), v_{ovM8} is the overdrive voltage of M_8 608, v_{dsM22} is the drain-to-source voltage of M_{22} 1024, and $v_{noffset}$ is the sum of the absolute values of the threshold and overdrive voltages of M_{23} 1028 (or M_{25} 1034). Normally, $v_{Tp3} < 0$ and $v_{dsM22} < 0$. M_{22} 1024 works in the linear region as a switch. It is possible that $v_{noffset} > -v_{Tp3} + v_{ovM8} + v_{dsM22}$. By comparing Eq. (23) with Eq. (35), it can be seen that the upper limit of the input common mode signal range desirably can be maintained greater than or equal to V_{DD} . Similarly, by comparing Eq. (24) with Eq. (36), it can be seen that the lower limit of the input common mode signal range desirably can also be maintained less than or equal to V_{SS} .

[0099] The above explanation of the present invention has been in the context of employing it in a differential amplifier. However, in a more general sense, the present invention relates to a method of extending an input signal range of any component that receives a signal. The skilled artisan would appreciate that, in this general sense, the present invention can be realized in any number of

embodiments in which a circuit first level shifts the voltage of the input signal and then processes the input signal.

[0100] FIG. 11 is a schematic diagram of a single-input amplifier 1100 of the present invention. Single-input amplifier 1100 comprises first amplifying transistor M_1 102 and second amplifying transistor M_9 706 with drain terminals connected at first node N_5 712. The source terminals of M_1 102 and M_9 706 are connected to V_{SS} 110. Load transistor M_3 504 is connected between V_{DD} 116 and N_5 712. In addition to providing active load, M_3 504 also acts as a current source for single-input amplifier 1100. The source terminal of M_3 504 is connected to V_{DD} 116. First bias voltage V_{biasp} 508 holds M_3 504 in saturation. The source terminal of voltage offset transistor M_{13} 722 is connected with the gate terminal of M_9 706 at second node N_8 724. The drain terminal of M_{13} 722 is connected to V_{SS} 110. Second current source transistor M_{14} 726 is connected between V_{DD} 116 and N_8 724. Second bias voltage V_{biasp3} 734 holds M_{14} 726 in saturation.

[0101] Input signal v_{i1} 118 is applied to the gate terminals of both M_1 102 and M_{13} 722 at input terminal N_{10} 736. Output signal v_{o2} 124 is produced at N_5 712, which is the output terminal. Configured as they are, M_{13} 722 and M_{14} 726 form source follower 744, where M_{13} 722 is the driven MOSFET and M_{14} 726 is the non-driven MOSFET. Thus, the voltage at N_8 724, v_{N8} , can be expressed as shown above in Eq. (27):

$$\text{Eq. (27)} \quad v_{N8} = v_{i1} - v_{TpM13},$$

where v_{TpM13} is the threshold voltage of M_{13} . Normally, $v_{TpM13} < 0$. Thus, M_{13} 722 acts to level shift v_{i1} 118 by the threshold voltage. Source follower 744 comprises an offset circuit. Thus, while M_1 102 directly amplifies v_{i1} , M_9 706 amplifies v_{N8} . Hence, M_9 706 indirectly amplifies v_{i1} because of the voltage drop across M_{13} 722.

[0102] For single-input amplifier 1100, the lower limit of v_{i1} 118 can be expressed as shown in Eq. (37):

$$\text{Eq. (37)} \quad v_{i1} > V_{SS} + v_{Tn2} - v_{poffset},$$

where v_{Tn2} is the threshold voltage of M_9 706, and $v_{poffset}$ is the sum of the absolute values of the threshold and overdrive voltages of M_{13} 722. It is possible that $v_{poffset} > v_{Tn2}$.

[0103] Likewise, the upper limit of v_{il} can be expressed as shown in Eq. (38):

$$\text{Eq. (38)} \quad v_{il} < V_{DD} + v_{Tn} - v_{ovload},$$

where v_{Tn} is the threshold voltage of M_1 102, and v_{ovload} is the overdrive voltage of M_3 504. Normally, $v_{Tn} > v_{ovload}$. Thus, the upper limit of the input signal range desirably can be maintained greater than or equal to V_{DD} , and the lower limit of the input signal range desirably can also be maintained less than or equal to V_{SS} .

[0104] In single-input amplifier 1100, M_1 102 and M_9 706 are NMOSFETs, while M_3 504, M_{13} 722, and M_{14} 726 are PMOSFETs. However, one skilled in the art would recognize that other transistor configurations could also be used.

[0105] FIG. 12 shows a flow chart of a method 1200 for extending an input signal range of a component that receives the input signal. In method 1200, at a step 1202, a voltage of the input signal is level shifted. This is done to compensate the input signal for bias voltages within the component that limit the voltages of the input signal to a range less than the desirable voltage range. The desirable voltage range spans between the voltages that supply power to the component. For example, offset transistors M_{13} 722 and M_{15} 728 level shift, respectively, input signals v_{il} 118 and v_{il} 120, by the threshold voltages.

[0106] Optionally, at a step 1204, a subcomponent from a plurality of subcomponents is selected to process the level shifted voltage. In an embodiment, the subcomponent is selected in response to a comparison between a common mode voltage of the input signal and a reference signal. For example, M_{11} 716 controls the current flow to differential pair 502 based on v_{ic} 736. Likewise, M_{12} 718 controls the current flow to differential pair 704. Based on the instantaneous value of v_{ic} 736, M_{11} 716 and M_{12} 718 act to control which of differential pairs 502, 704 dominates the other during amplification. When a greater portion of the total current flows through M_{12} 718, differential pair 704

provides more amplification than differential pair 502. Thus, differential pair 704 is selected to process the level shifted voltage.

[0107] At a step 1206, the level shifted voltage is processed within the component. In an embodiment, the offset voltage is amplified within the component. For example, differential pair 704 amplifies v_{N8} and v_{N9} , thus processing the level shifted voltages. Because of the voltage drop across M_{13} 722 and M_{15} 728, differential pair 704 indirectly amplifies v_{i1} and v_{i2} .

Conclusion

[0108] While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example, and not limitation. It would be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention. Thus the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.